ENHANCING THE GEOSTATIONARY LIGHTNING MAPPER FOR IMPROVED PERFORMANCE

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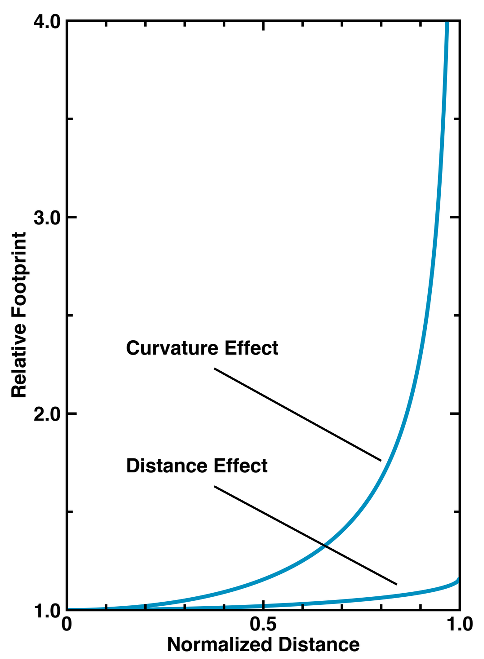
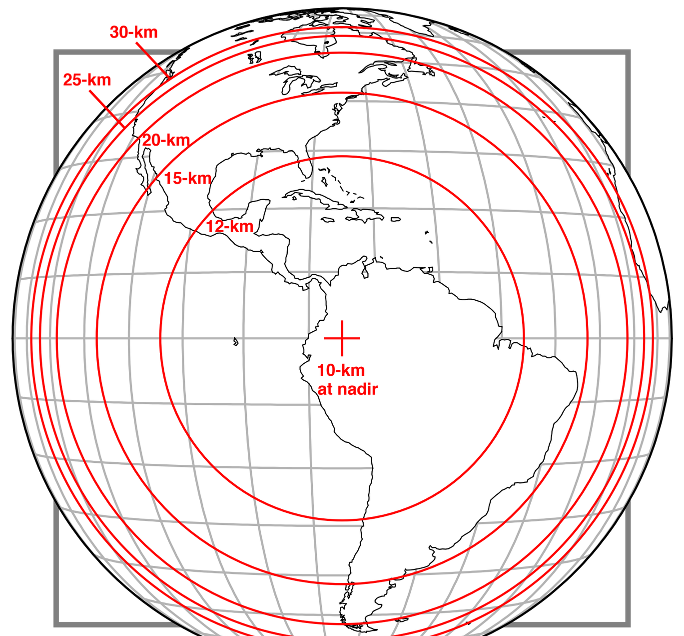
Image Resolution Away from Nadir

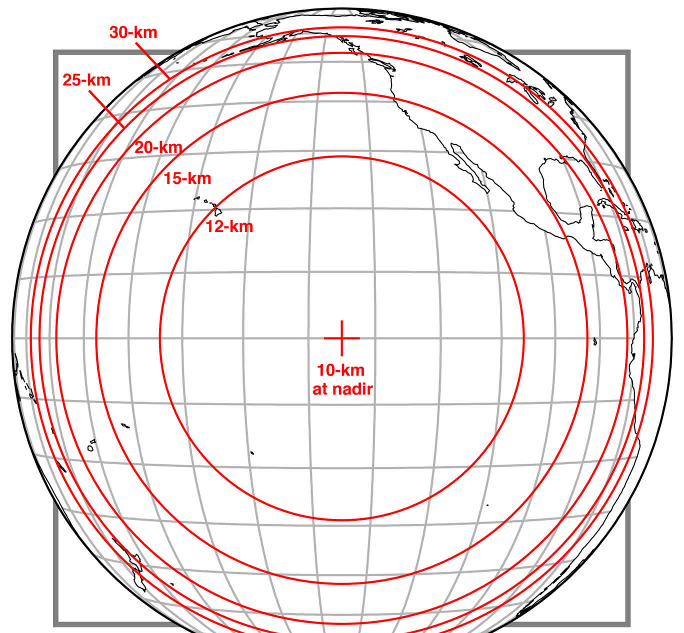
For satellites in geostationary orbit the maximum resolution is generally at nadir, with the image resolution getting worse as you move away from the sub-satellite point. The loss in resolution is due to two factors: the foreshortening of earth features due to earth curvature and the increasing diagonal distance from the satellite to the earth's surface. The curvature effect is directed in the radial directions only, while the distance effect applies to both the radial and lateral directions.

For geostationary satellites, the curvature effect is the dominant factor and the distance effect is relatively minor. The figure below shows the magnitude and pattern of the curvature and distance effects as a function of the distance away from nadir (expressed in non-dimensional units with the edge of the visible earth disk defined as unity). For many areas of interest, including CONUS, the radial foreshortening results in a loss in image resolution by as much as a factor of 2.5 to 3.0 and limits the extent of useful area coverage.

The GLM PORD's definition of "full-disk" coverage corresponds to limiting the loss in nadir resolution to a factor of 2.5 (or 25-km resolution for a design with a nadir resolution of 10-km).







The Geostationary Lightning Mapper (GLM) will be a single-channel, near-IR optical instrument designed to detect and locate lightning strikes from geostationary orbit (see Goodman, et. al, 2008). As a component of the new GOES R spacecraft, the instrument will provide continuous full-disk lightning observations from a fixed, downward pointing telescope with a staring sensor based on a large 2-D CCD detector array.

The GLM Performance and Operational Requirements Document (PORD) calls for full-disk coverage, defined from the perspective of the GOES-R spacecraft as a square detection area (corresponding to the CCD array) centered at nadir and extending just under 53° in both the north-south and east-west directions. The instrument's optics are also required to provide coverage out to a minimum of 59° from nadir (92% of the way from nadir to the edge of the visible earth disk). Going into the Formulation Phase design studies (e.g. Boccippio and Schaefer, 2006), the GLM's resolution target was to have a 10-km (Ground Sample Distance, GSD), or better, with a goal of 0.5 km. For the specified coverage area, a 1024 by 1024 CCD sensor array would provide a nadir resolution of just under 10-km.

Johnson (2006 and 2007) discusses the possible use of an optical adapter (termed the GeoObs adapter) to correct for earth curvature effects and provide essentially uniform resolution imagery from a sensor in geostationary orbit. This adapter concept seems to be particularly well suited for likely GLM design concepts, but is a hardware enhancement that would have to be incorporated into the instrument design before launch.

The GeoObs adapter would progressively stretch the earth image in a radial direction, with increasing stretching the further you get from nadir, at exactly the rate required to offset the natural foreshortening of earth features due to earth curvature (and to a lesser extent due to the increasing oblique viewing angles). The adapter would leave the regions near nadir unchanged, but would modify the overall proportions of the disk image so as to preserve essentially uniform resolution in any radial direction.

While Johnson (in both his 2006 and 2007 papers, as well as in the current discussion) places an emphasis on trying to generate uniform resolution imagery across the full earth disk, a similar stretching on a more modest scale could be used to minimize or restrict the normal loss in resolution as you move away from nadir without attempting a full correction.

Strictly speaking, it is impossible to provide truly "uniform resolution" imagery across a full disk image of a sphere (earth) as seen from geostationary orbit. This reflects a fundamental physical limitation which makes it impossible to simultaneously depict accurately the linear dimensions, area, and shape of features on a 3-dim-ensional object in a 2-dimensional image. This is a fundamental problem in cartography (Snyder, 1987).

Nevertheless, there are a wide variety of transformations (mappings) of the spherical earth that could reasonably be called "uniform resolution", whether through simple correcting for the loss in resolution in a radial direction due to earth curvature, or by more sophisticated transformations that can emulate standard map projections (in their equatorial implementations) such as Lambert Equal-area, Equidistant, or Stereographic. These specific map projections are all members of the azimuthal family of map projections, which differ from each other only in their treatment of distances from a reference point in the radial direction. Since the normal perspective view of the earth from geostationary orbit can also be considered to be a member of this same azimuthal family of map projections, the GeoObs adapter provides a potential functionality for transforming earth observations directly into a reference frame that emulates standard map projections.

The distinguishing feature of the desired transformations is a dramatic improvement over the normal satellite perspective images which experience extreme distortion and loss of resolution as you move away from nadir.

For this paper, the potential GeoObs transformations shown in the figures are all based on the Lambert Equal-area map projection. This means that each pixel of data collected by the CCD will represent an equal area on the earth's surface.

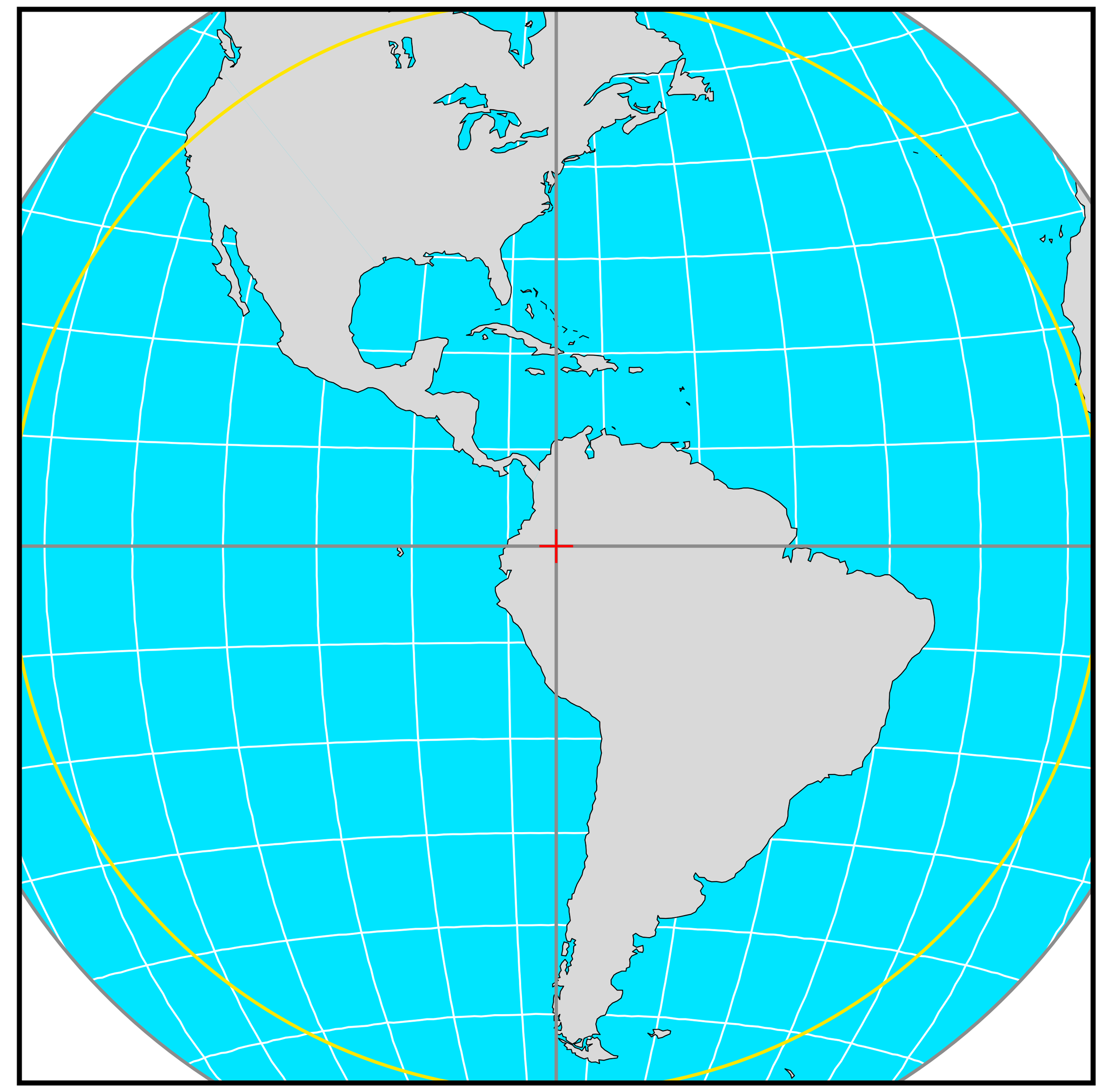
While 10-km resolution (at nadir) may often be adequate, resolutions of 20 to 25-km over CONUS will be a potentially serious limitation for many lightning applications. Optically transformed lightning imagery to provide full disk uniform resolution coverage should provide better data for model input and for integration with other data sources such as radars, and would be more appropriate for decision support systems (e.g., nowcasting of severe weather and tornados) and for long-term climate records. Uniform resolution observations are particularly well suited for many processing algorithms, such as Boccippio's radiance-weighted centroid approach for the analysis of lightning pixel clusters (see Boccippio and Schaefer, 2006). Enhancements of this sort are particularly valuable since they are applied before the observations are made and directly enhance the quality of the observation, and are not just a software remapping of the imagery after it is collected.

A transformation to uniform resolution coverage across the full earth disk can improve lightning observations in terms of both area coverage and resolution, but with trade offs that need to be considered. Radial stretching of the normal perspective view of the earth while maintaining the image resolution at nadir makes the image larger. This reflects a real gain in resolution without over-sampling the equatorial areas near nadir, but at the cost of requiring a larger CCD sensor array. Most importantly, the transformed image will also maintain its resolution as you move away from nadir, resulting in a significant increase in the resolution over critical areas (such as CONUS) that are relatively far from nadir.

The improvement in the sensor resolution towards the edge of the earth disk also makes it attractive to expand the geographical coverage area to take additional advantage of the high resolution imagery. This extended area coverage can "fill in" the corners of the CCD array, or may justify a design change to incorporate a larger CCD sensor array.

An alternative to enlarging the CCD would be to shrink the transformed image to fit within a smaller, standard-sized CCD, trading off a small loss in nadir resolution for larger area coverage and higher overall resolution. Cutting back from an initially targeted 10-km nadir resolution to a transformed image with 12-km resolution across the full earth disk, for example, would still produce a significant improvement in the image resolution over CONUS, going from 20 or 25-km to 12-km.

2048 x 2048 CCD SENSOR MOSAIC



2048 x 2048 CCD Mosaic
6.5-km Resolution
Enlarged Full Disk Coverage

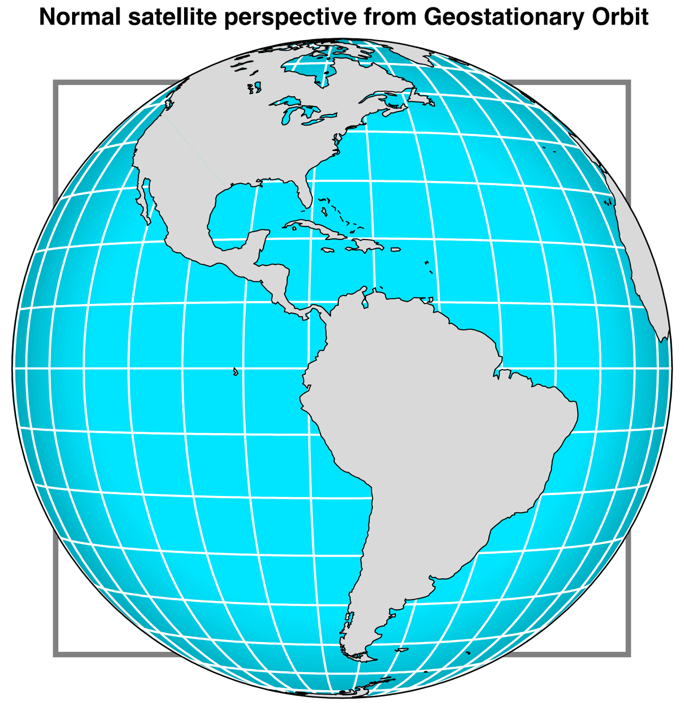
GEOOBS TRANSFORMATIONS (FULL DISK UNIFORM RESOLUTION)

These transformations require a hardware modification that would have to be designed into new remote sensing instruments before launch. While the transformations may be able to be emulated by software remapping of the imagery collected by conventional sensors, the remapping process does not improve the underlying quality of the observation. For that you need a hardware enhancement.

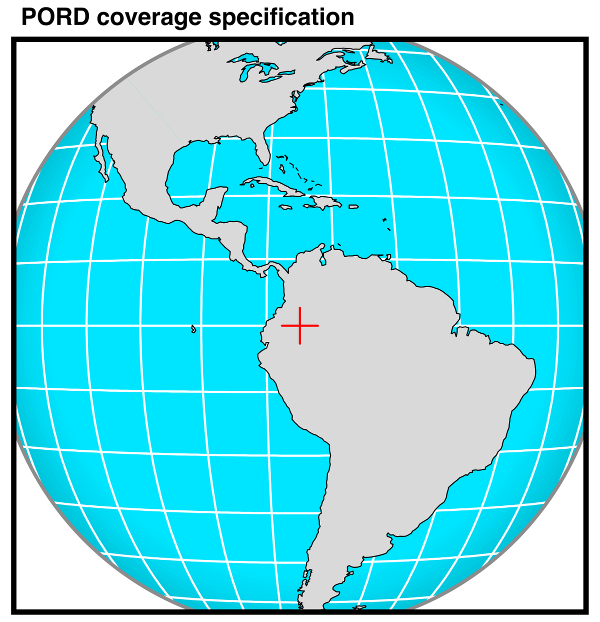
1024 x 1024 CCD
6.5-km Resolution
Enhanced North America Coverage

GOES-EAST

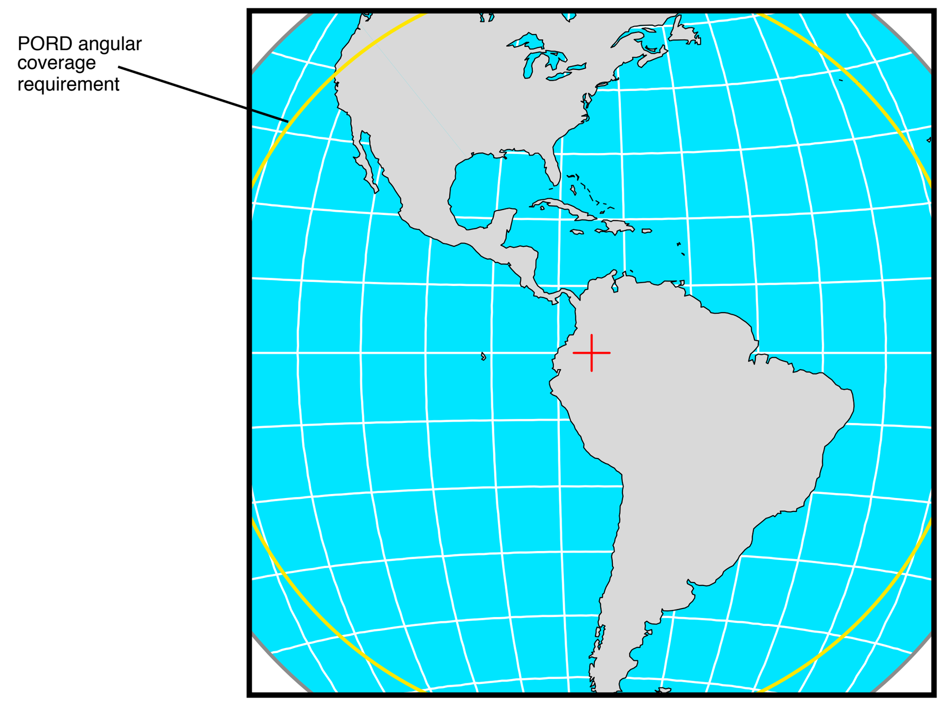
Normal satellite perspective from Geostationary Orbit



PORD coverage specification



ENLARGED CCD



STANDARD CCD

1024 x 1024 CCD
10-km Resolution at Nadir
Full PORD Coverage

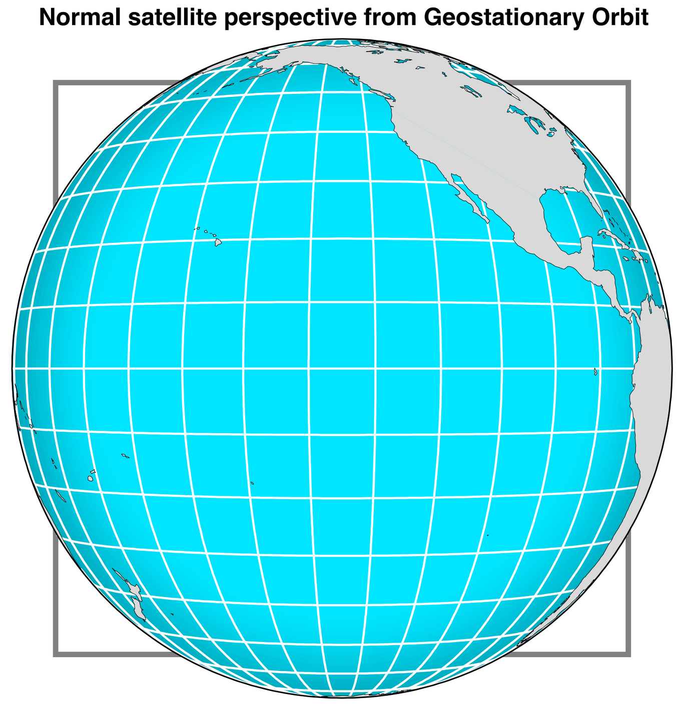
CUSTOM 1225 x 1225 CCD
10-km Resolution
Full PORD Coverage

1024 x 1024 CCD
12-km Resolution
Full PORD Coverage

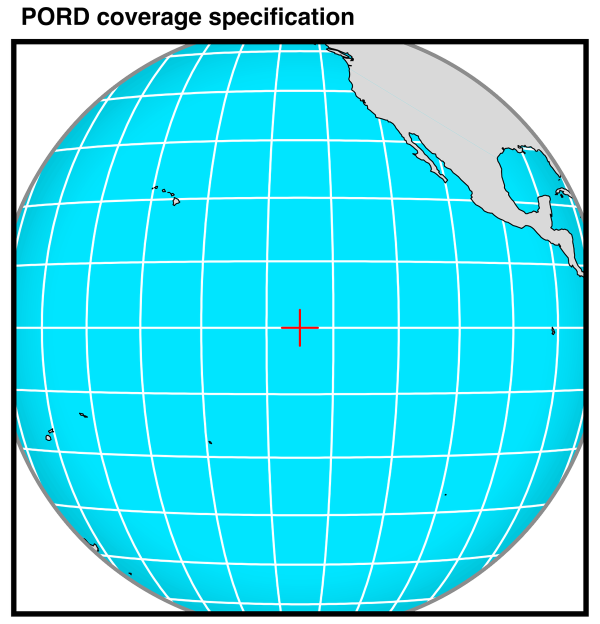
1024 x 1024 CCD
10-km Resolution
Limited Area Coverage

GOES-WEST

Normal satellite perspective from Geostationary Orbit



PORD coverage specification



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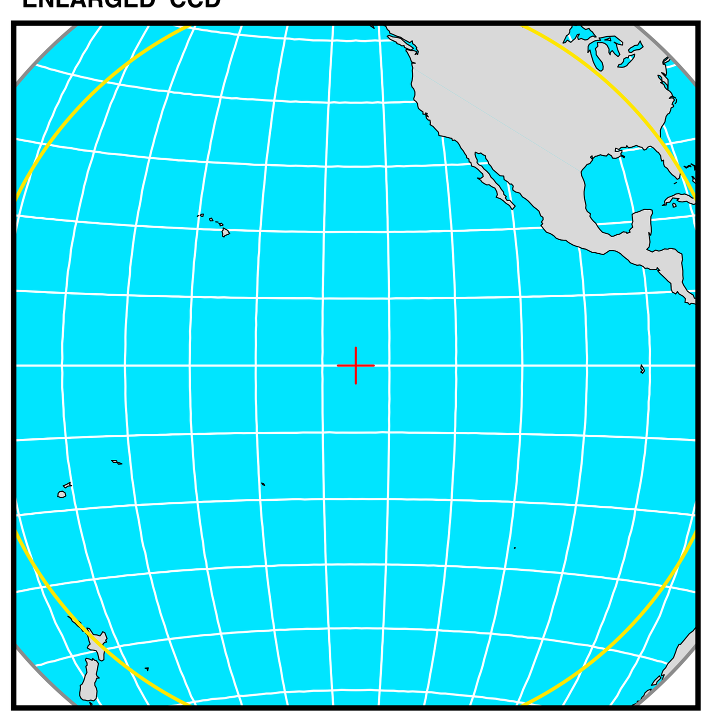
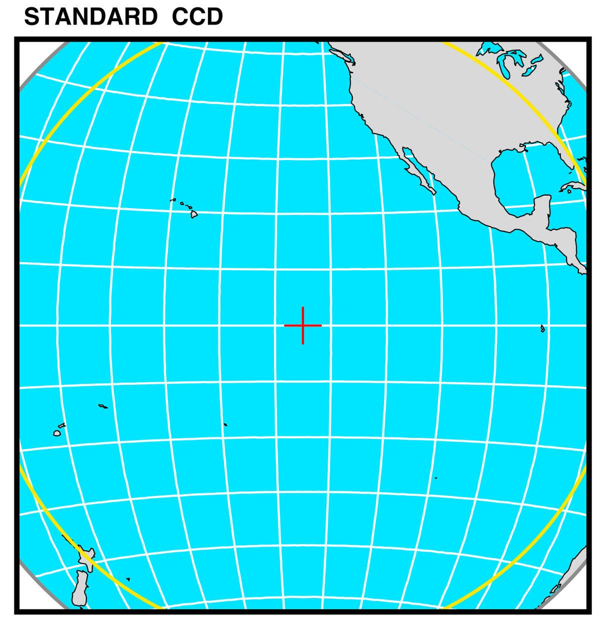
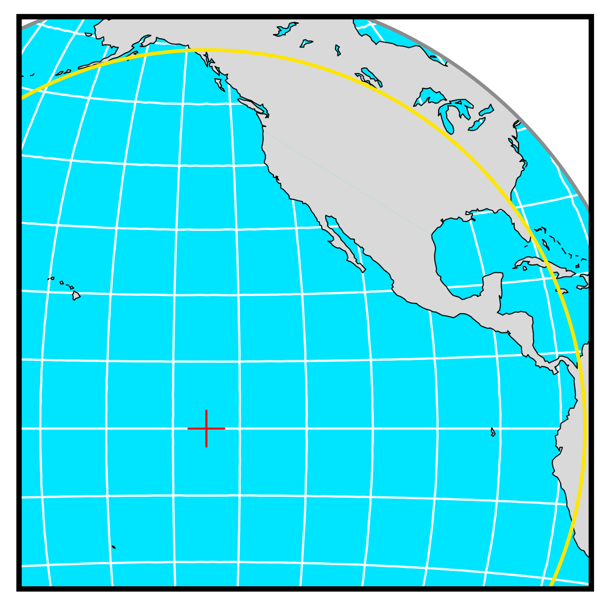


STANDARD CCD





REFERENCES:

Boccippio, D., and J. Schaefer, 2006: Geostationary Lightning Mapper (GLM), 4th GOES Users' Conference, Office of Systems Development, NESDIS (NOAA), Broomfield, CO, 1-3 May 2006.

Geostationary Lightning Mapper (GLM), Performance and Operational Requirements Document (PORD), Geostationary Operational Environmental Satellite (GOES), GOES R Series, 417-R-GLMPORD-0057 (Version 2.2), Goddard Space Flight Center, NASA, 25 May 2007, 26 pp.

Goodman, S.J., R.J. Blakeslee, and W. Korshak, 2008: Geostationary Lightning Mapper for GOES-R and Beyond. 5th GOES Users' Conference, Office of Systems Development, NESDIS (NOAA), New Orleans, LA, 21-24 January 2008.

Johnson, D.B., 2006: New technology sensors for correcting satellite imagery for earth curvature effects. Asia-Pacific Remote Sensing Symposium, Proceedings of SPIE, Volume 6405 (64050T), 10 pp.

Johnson, D.B., 2007: An Optical Device for Correcting Geostationary Satellite Imagery for Earth Curvature Effects: Making METEOSAT Imagery over Europe as good as it is over Equatorial Africa. 2007 EUMETSAT Meteorological Satellite Conference, Amsterdam, 24-28 September 2007, 5 pp.

Snyder, J.P., 1987: Map Projections — A Working Manual. U.S. Geological Survey Professional Paper 1395, U.S. Government Printing Office, Washington, DC, 383 pp.